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FARM RESERVOIRS

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FARMERS' BULLETIN 828

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L. W. PAGE, Director

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THE principal purpose of farm reservoirs is to store water for irrigating gardens, orchards, and truck. The water from farm reservoirs is used also in many cases for stock and for domestic purposes. If used in the home, utmost care should be exercised to keep the water unpolluted.

There are several principal types of reservoirs, differing according to the methods of construction, the purposes for which they are to be used, and the location of the lands upon which they are placed.

This bulletin gives practical information to those who intend to build or are operating farm reservoirs. The chief features of such structures are discussed first, without regard to any particular kind, and, afterwards, the various kinds which are adapted to the storage of water on farms are described.

FARM RESERVOIRS.

CONTENTS.

RESERVOIRS suited to the needs of individual farmers and small groups of farmers form the subject of this bulletin. The main purpose of such reservoirs is to store water for the irrigation of gardens, orchards, and truck farms, but they may also serve to store water for stock and to provide domestic supplies for farm dwellings. Farm reservoirs are used most commonly in conjunction with pumping plants operated by gasoline engines, windmills or electric motors. Many pumping plants have been installed in recent years for irrigation purposes, and this development has created a demand for storage facilities to retain the water lifted by the pump overnight, and thus provide a large irrigation stream for the following day.

PURPOSE OF BUILDING A RESERVOIR.

The purpose which a farmer has in mind in building a reservoir will go far to fix its essential features. If he intends to use any part of the stored water for drinking or even culinary purposes, the entire supply must be kept free from pollution.

On the other hand, if the supply is intended for irrigation only, the purity of the water need not be considered. In building a reservoir for use in connection with a pumping plant, the size, elevation and location of the former should be adjusted carefully to the needs of the latter and to the land to be watered, one essential feature being that the outlet be somewhat higher than the area served. When the main purpose is to store the small flow of a spring or the discharge of a small pump until enough water can be had to form a large stream or head, as it is called, and thus water a larger area in a shorter time, the outlet of the reservoir should be large enough to permit this to be done. Again, if the reservoir is intended for both irrigation and the watering of farm animals, care should be taken in planning and building the reservoir to prevent damage being done by the trampling of stock.

WATER SUPPLY FOR FARM RESERVOIRS.

The most common source of supply for such reservoirs is the well, from which water is raised to the necessary height by a windmill, internal-combustion engine, or electric motor. The reservoir is located as near as practicable to the well, and the discharge from the pump leads directly to the reservoir with a branch to the head of the supply ditch, thus permitting the well water either to be stored or used directly on the land.

The flow from springs, brooks, flowing wells, and small creeks forms another source of supply. This is often too small for rapid and effective irrigation when used continuously, and storage is resorted to in order to obtain a large head and also to collect the flow overnight for use the following day or over several days for use during a drought. Springs and other small sources of running water may be made to serve a variety of useful purposes if the proper equipment is provided for their full utilization. Where there is sufficient fall, a part of such water may be piped directly to the house and barn and the balance allowed to flow into a pond or small reservoir, from which it is conveyed by pipe to an irrigated field, orchard, or vegetable garden (fig. 1). In cases where there is no fall or not enough, the water may be pumped first to the house and then allowed to flow by gravity to the

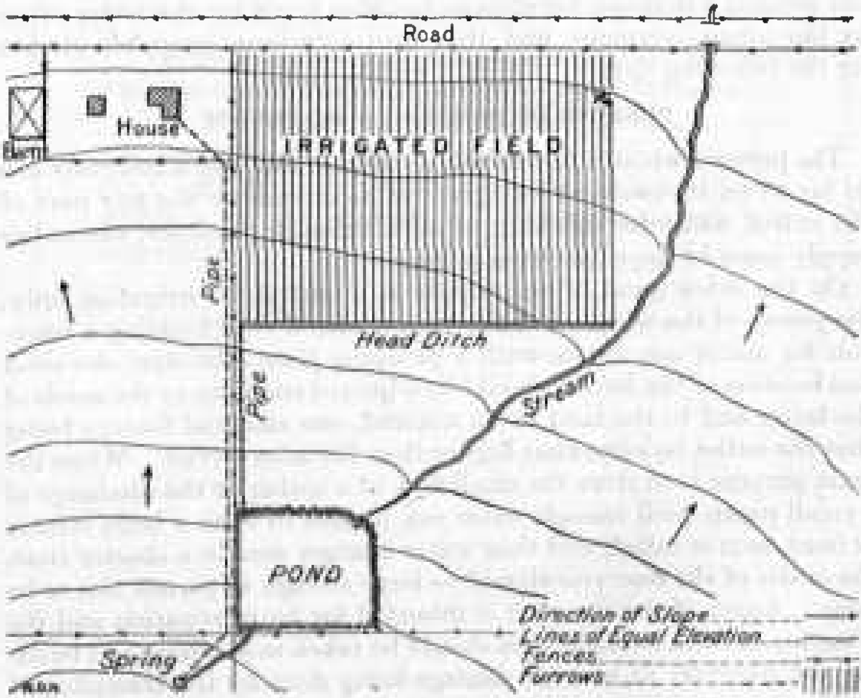

FIG. 1.—Showing how a New York dairy farmer utilizes a spring.

barn and corral and thence to a pond, from which it can be withdrawn for irrigation purposes (fig. 2).

Owing to natural causes or the careless use of water in irrigation, fertile fields often become water-logged. In the majority of cases it is feasible to drain these low marshy places and apply this water to other tracts that may be too dry. If the amount of water withdrawn is small, a reservoir to store enough to make an irrigation head often is a profitable investment.

In that borderland between humidity and aridity, known as the Great Plains area, and throughout the arid region, the so-called "dry creeks" carry considerable water at times. Part of this run-off often can be led into a reservoir and stored for future use in watering stock and irrigating land.

In the Atlantic and East Central States, and, in fact, throughout the entire humid region, water to fill farm reservoirs generally can be obtained readily at low cost from springs, lakes, streams, and shallow wells. Bogs or muck beds of limited areas also abound on eastern farms, particularly in the Atlantic Coast States. These often can be converted at small cost from mosquito-breeding grounds into serviceable reservoirs.

SELECTION OF SITE.

The location of the reservoir will depend largely on two factors—the source of the water supply and its utilization. If the water is pumped from a well, the well and reservoir, as has been stated, should be as near to each other as practicable, and both should be

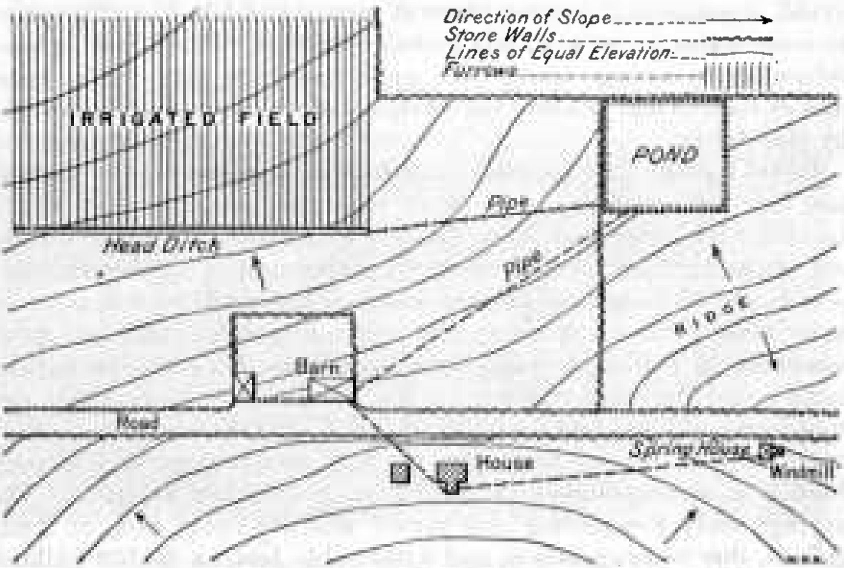

FIG. 2.—The utilization of a spring for domestic, stock, and irrigation purposes.

located on the highest ground to be watered. Where a reservoir is to be fed from a stream, a part of the flow may be stored in the stream bed or be diverted through a pipe, flume, or ditch to a better site some distance away. In the selection of sites for the larger community reservoirs care must be exercised to make sure that water can be stored at small expense per unit volume, and such factors as the character of the materials to be used, the nature of the foundation, porosity of the soil, dependability of the inflow, and the like, likewise are to be carefully considered. The farmer, on the other hand, has less choice of selection. He may be obliged to build a reservoir on a poor site in order that it may be placed near a pumping plant, or for other reasons arising from his needs or the conditions on his farm.

LOSS OF WATER FROM RESERVOIRS.

Water escapes from unlined earthen reservoirs in two ways other than through the outlet or wasteway. A part of the contents is absorbed by or else percolates through the materials forming the bottom and sides, and another part is vaporized at the surface and passes off into the air. Were it not for the relatively large losses due to absorption and percolation, usually termed seepage losses, the large majority of reservoirs would be much more efficient. It is only in rare instances that the contents of reservoirs are increased by the inflow of seepage water. Since seepage losses may be regarded as one of the worst defects of the common practice of storing water on farms, it can not be too carefully considered beforehand, so as to avoid, if possible, the expenditure of money and labor in attempting to store water in material too porous to hold it. The following brief references to seepage losses from small reservoirs may convey some idea of their extent and how the efficiency of reservoirs may be lowered by this defect.

In 1914 a circular reservoir, 172 feet in diameter at the bottom and 182 feet at the top, was built near the pumping plant of the Garden City substation near Garden City, Kans. It was formed out of the light silt loam of which the upper part of the farm is composed, and although the bottom was puddled, little care appears to have been taken in building the circular embankment and more especially in making a water-tight connection between the natural surface and the embankment. A few weeks after the reservoir was completed, it was filled with well water and measurements were made [1] of the loss of water due to both evaporation and seepage from 6 p. m. September 11 to 7 a. m. September 21, 1914. The average daily loss during this period was 350 cubic feet, or 2,625 gallons, due to evaporation, and 8,040 cubic feet, or 60,300 gallons,

[1] The seepage and evaporation losses on this reservoir were determined by G. S. Knapp, Agent of the Office of Public Roads and Rural Engineering.

due to seepage. Expressed in another unit the loss for both evaporation and seepage was 0.35 cubic foot per square foot of wet area in 24 hours.

Water measurements were also made on the same reservoir during the irrigation season of 1915, the results of which showed that the pump discharged into the reservoir exclusive of all losses due to evaporation 75.23 acre-feet, that the amount withdrawn through the outlet was 52.52 acre-feet, leaving a balance of 22.71 acre-feet unaccounted for to be attributed to seepage loss. Since this water was raised through an average lift of 130 feet at a cost for fuel, oil, and repairs of $3.13 per acre-foot, the waste of water caused by seepage increased the cost of pumping for the season to the extent of $71, or 30 per cent of the total cost.

In 1916 the loss due to seepage from the Dealy reservoir near Fort Collins, Colo., was ascertained. This earthen reservoir holds 8.6 feet of water when full, covers an area of 7.6 acres, has a capacity of 29.5 acre-feet, and the bottom and sides are composed of a heavy clay loam. The maximum loss was nearly 0.2 cubic foot per square foot of wet area per 24 hours and the average daily loss from May 25 to September 6, 1916 was 0.08 cubic foot per square foot of wet area.

In 1905 a rectangular reservoir, 100 feet wide by 200 feet long and 3 feet deep, was built in a porous soil and subsoil on the substation near Cheyenne, Wyo. (fig. 3). Tests made before the lining was laid showed an average loss in 24 hours of 0.72 cubic foot per square foot of wet area due to evaporation and seepage.

A reservoir of about the same dimensions was built at Eads, Colo., in 1907 to store water pumped from wells for use on an experiment

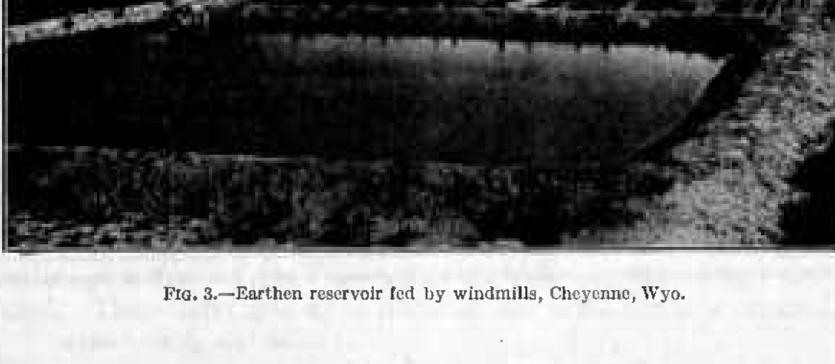

FIG. 3.—Earthen reservoir fed by windmills, Cheyenne, Wyo.

farm. The material forming the reservoir consisted of a sandy loam and before it was lined the seepage losses averaged 0.25 cubic foot per square foot of wet area per 24 hours.

Seepage losses likewise occur in earthen canals. A large number of seepage tests on canals have been made and recorded.[1] From such records and other available data pertaining to reservoirs Table 1 has been prepared.

TABLE 1.—*Loss by seepage in reservoirs composed of different materials.*

Kind of material.	Loss per square foot of wet surface in 24 hours.	Loss per 100 square feet of wet surface in 24 hours.	Loss per acre in 24 hours.
	Cubic feet.	*Gallons.*	*Gallons.*
Retentive clay	0.05 to 0.15	37 to 112	16,120-48,790
Clay loam	.15 to .50	112 to 375	48,790-163,350
Sandy loam	.50 to 1.00	375 to 748	163,350-325,830
Porous material	1.00 to 2.00	748 to 1,496	325,830-651,660

After a reservoir has been filled, the loss of water may be found readily by measuring the sinkage in a given time. To do this set a gauge in the reservoir and when the weather is settled, there being neither rain nor wind, close the inlet and outlet gates so that no water will pass through either, and read the gauge. Then in 24 hours or at the end of any multiple of 24 hours, again observe the gauge and note the difference in elevation, or sinkage, of the surface of the water. This difference as shown by the two readings of the gauge, when expressed in inches and divided by 12 will give the loss of water in cubic feet per square foot of reservoir surface during the time of the test. Losses due to both evaporation and seepage will be included in the results found.

Whenever it is desirable to separate these two losses, it may be done by ascertaining the total loss and also the loss due to evaporation. The latter may be found by digging a hole in the top of the embankment of the reservoir, placing therein an ordinary galvanized-iron wash tub or garbage can and filling it to within a couple of inches of the top with water taken from the reservoir. The loss of water in any number of days can then be found by measuring from the lip of the tub to the surface of the water at the beginning and end of the period. About three-fourths of the daily loss by evaporation as determined by the small can would represent the daily loss from the surface of the reservoir. Deducting this loss from the total daily loss due to both evaporation and seepage as indicated by the reservoir gauge would give the loss due to seepage.

[1] Concrete lining as applied to irrigation canals. By Samuel Fortier, Bul. 126, U. S. Dept. of Agr., 1914.

Seepage losses may be prevented almost entirely by lining the reservoir with concrete. The methods employed are briefly described under "Type No. 6." Such a lining may cost, however, as high as 10 cents per square foot or more than $1,000 per acre-foot of water stored. Since the interest on the cost of a concrete lining might amount to more than the value of the water wasted annually, it is well to consider ways and means of making the reservoir reasonably water-tight by cheaper methods. Much can be done toward this end when the reservoir is being built. To guard against the loss of water under the embankment and along the ground surface, a trench should be dug where the center of the embankment is to rest and a water-tight embankment built above in some such manner as is outlined on pages 24 to 33. When the necessary steps are taken to insure a water-tight embankment and to guard against the escape of water beneath it, the only porous parts remaining are the bottom of the reservoir and parts of the inner slopes formed in the natural ground. To lessen the percolation of water through such parts, they should be well soaked first and afterwards lined with some cheap impervious material. Where turbid water, carrying a high percentage of either clay or silt, can be had, it should be run into the reservoir, allowed to settle and then withdrawn to give place to another filling of turbid water. This operation, when repeated a sufficient number of times, will greatly lessen the seepage loss.

If clay or silt can not be transported in the manner just described, clay should be hauled by teams, if it can be found within an economical hauling distance. In lining with clay a reservoir intended for irrigation purposes only, a good plan to follow is to cover the bottom and porous slopes with a mixture of clay and coarse gravel to the depth of several inches and when sprinkled or otherwise moistened, use the site as a feeding ground for sheep or other farm animals. In cases where this plan is not practicable, the layer of clay should be as thoroughly pulverized as possible, the coarse gravel added and the mixture moistened and tamped by hand. The addition of coarse gravel ranging from the size of peas to that of walnuts forms a clay concrete more stable and compact than clay alone and none the less impervious.

INLETS.

Where a reservoir is built in the bed of a stream an outlet pipe or other means of conducting water into it is not necessary. Where a reservoir is located near a stream the waters of which can be run into it by gravity, a ditch or flume may suffice. In the large majority of cases, however, water is conveyed to farm reservoirs under more or less pressure and pipes are about the only equipment that can be used. These differ greatly in material and make and it is important

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to select for both inlet and outlet structures a kind adapted to the needs of the site, the capacity of the reservoir, and other conditions.

The ordinary sewer pipe made of shale or clay may be used for inlet pipes laid on grade or under low heads not exceeding 15 feet for the smaller and 10 feet for the larger sizes. This pipe is made in sizes ranging from 3 to 24 inches in diameter and in lengths of 2½ and 3 feet and is suitable for a fairly large flow under a low pressure. It is both cheap and durable and may be serviceable providing skill and care are exercised in selecting the pipe and in laying it so as to avoid leaks in the joints. It is not suitable pipe for conveying water from a pump to a reservoir above the pump since the pressure and pulsations created by the pump are apt to cause leaks. What has been stated regarding clay pipe will also apply to concrete pipe which is not reinforced in any way.

Machine-banded pipe made of staves of redwood or fir and wound with galvanized steel wire is used extensively in many of the Western States. It compares favorably with either clay or concrete pipe as regards cost and has an added advantage in being able to withstand reasonably high pressures. Its chief disadvantage lies in the fact that the wood of which it is composed, and more particularly the wooden collars which form the joints, is subject to early decay. For this reason it is not a suitable pipe to use for reservoir outlets.

Steel-riveted pipe is made in a large number of sizes ranging from 4 to 30 inches and over in diameter and capable of withstanding heads of 50 to 300 feet. Each joint of pipe is made of a single sheet of steel which is sized, punched, rolled, and riveted. Several of these joints are then riveted together, making a shipping length of about 30 feet. Each length is galvanized or immersed in a bath of hot asphalt before being stacked up in the shipping yards. For all sizes up to 12 inches designed for ordinary pressures the lengths are simply driven together, the smaller joint of one end telescoping the larger joint of the next length. For high pressures and large sizes the circular seams are single-riveted and sometimes split calked. During the past five or more years lighter and less expensive pipe of galvanized iron from 20 to 24 B. W. gauge, both coated and uncoated, has been used extensively in certain portions of the Northwest. The steel or iron riveted pipe may be used wherever the machine-banded wooden pipe is suitable. The former costs more than the latter, but is more durable.

A still higher-priced pipe commonly used to convey water from a pumping plant to a reservoir consists of a lap-welded steel pipe. This may be purchased in all standard sizes from less than an inch up to 12 inches and more in diameter. It is best to specify that it be galvanized, since the untreated or "black" pipe is likely to corrode and thus lessen its efficiency and durability.

Unless there are good reasons for doing otherwise, inlet pipes should be laid through and not over the embankment of reservoirs connected with pumping plants. In other words, the inlet pipe should enter the reservoir in some such manner as is indicated in the sketch, figure 4, having its outlet enlarged as shown. Inlet pipes from pumps to reservoirs also should be laid with the fewest possible number of bends and where bends must be used they should have long radii. The saving in power which these improvements will bring about may amount to a considerable sum in the first cost of the plant and the yearly expenditure for fuel oil or current The loss of power and the consequent lowering of the efficiency of the plant which high deliveries entail are shown in figure 5, where water is pumped from a well and then permitted to fall a distance of over 12 feet to the bottom of a concrete-lined reservoir.


FIG. 4.—Discharge end of inlet pipe to reservoir.

OUTLETS AND GATES.

All the kinds of pipe noted under "Inlets" with the possible exception of wood pipe, may be used for outlet pipes. To these should be added cast-iron pipe, which is well adapted to this purpose. The main things to consider in building outlets are prevention of leaks and breaks, sufficient capacity, and a ready means of turning on and shutting off the flow of stored water. The simplest kind of an outlet consists of a pipe to which is attached a valve or gate, laid with its upper end on the floor of the reservoir and extended under the embankment on a slight grade to a point a few feet beyond the toe of the outer slope. Usually, however, conditions call for something more. For example, trash, weeds, or débris may collect at the entrance to the outlet pipe and choke off or greatly reduce the discharge. To guard against this a box, preferably of concrete, is built around the entrance, having one end or the top or both open and covered

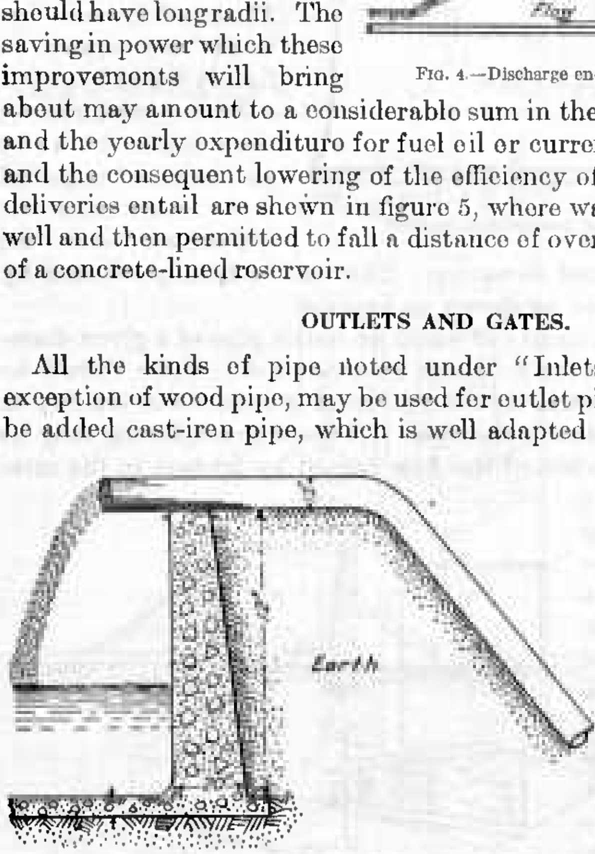

FIG. 5.—Showing waste of power in raising water and then permitting it to fall to the surface of the water in the reservoir.

with a heavy wire screen. It is likewise good practice to build a cut-off wall of concrete or well-rammed clay around the upper part of the outlet pipe to prevent the escape of water along its smooth exterior surface. Again, some kind of a footbridge extending from the top of the embankment to the valve stem is necessary in order to operate the valve. These additional features are shown in figures 6 and 7.[1]

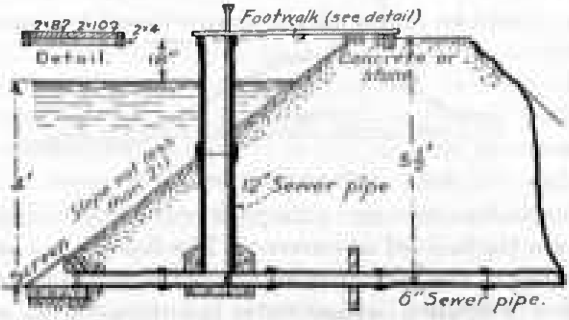

FIG. 6.—Outlet pipe and gate for small reservoir.

It is sometimes an advantage to have an outlet so adjusted that water can be withdrawn from the reservoir at any desired elevation. This can be readily effected by the use of flash boards, as shown in figure 8.

In estimating the quantity of water an outlet pipe of a given diameter will discharge under a known reservoir head, there should be taken into account several factors that tend to reduce the velocity or pressure and thereby lessen the flow. Of these the following may be named: (1) A retardation of the flow caused by friction in the interior of the pipe; (2) a loss of head in passing through a valve or other gate structure; (3) a loss of head at entrance; and (4) a lessening of the pressure and flow in passing through a screen. The effect of each one of the above in turn depends on a number of variable conditions which make it difficult to present any one set of figures that will apply to all. The following table, therefore, of outlet discharges should be considered as giving merely approximate volumes under such average conditions as are found in practice.

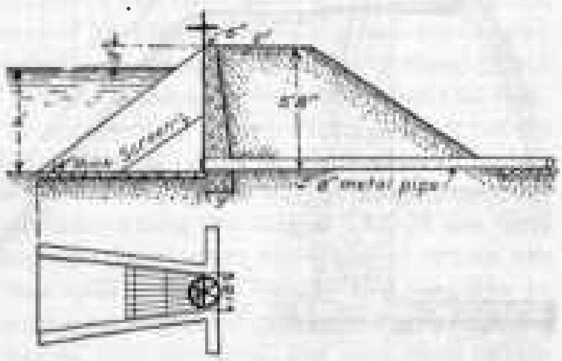
FIG. 7.—Cross section of small reservoir through gate and pipe.

[1] The drawings contained in this bulletin were made, for the most part, by F. C. Scobey, Irrigation Engineer, of the office of Public Roads and Rural Engineering.

TABLE 2.—*Discharges of outlet pipes of various diameters in lengths of 30 to 40 feet under different heads and provided with valves and screens.*[1]

Head over center of opening.	4-inch.		6-inch.		8-inch.	
	Cubic feet per second.	Gallons per minute.	Cubic feet per second.	Gallons per minute.	Cubic feet per second.	Gallons per minute.
Feet.						
1	0.35	157	0.52	233	1.3	580
2	.46	206	1.06	476	2.0	900
3	.58	260	1.42	637	2.5	1,120
4	.69	310	1.69	758	3.0	1,350
5	.79	355	1.91	857	3.5	1,570
6	.89	399	2.09	934	4.0	1,800

[1] Based on experiments made by V. M. Cone and R. L. Parshall at the hydraulic laboratory of the Colorado Agricultural Experiment Station at Fort Collins, Colo., July, 1916.

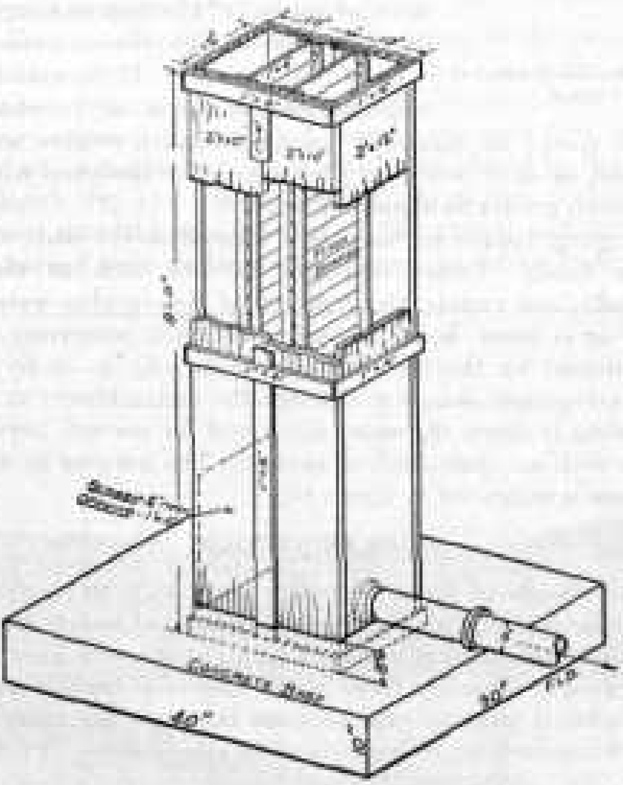

FIG. 8.—Showing the use of a double set of flash boards as an outlet for a small reservoir.

WASTEWAYS.

In all reservoirs fed direct from streams and formed by earthen dams, ample provision should be made to draw off the surplus water through a wasteway and thus prevent the water in the reservoir from rising above the high-water limit. This limit must always be placed

at a safe distance below the top of the earthen dam. Many reservoirs have failed as a direct result of defective wasteways. They are either too small, not in the right place, or are poorly designed and constructed. Since it is impossible to estimate closely the flood flow of the creek or stream which feeds the reservoir, the wasteway should be built of ample capacity to secure a rather wide margin of safety. It should be located as far away from the dam as practicable. When the nature of the ground will permit, an excellent and safe wasteway is formed by excavating the material down to the flow line in a low gap of the margin of the reservoir. When this is not feasible, a shallow canal may be dug around one end of the dam and carried down stream far enough to prevent damage to any part of the structure. If the material of the wasteway is liable to scour, the channel may have to be paved or flumed. Since wasteways receive water at a state of rest or slow velocity, they should be designed with flaring inlets on steep grades as shown in figure 9.

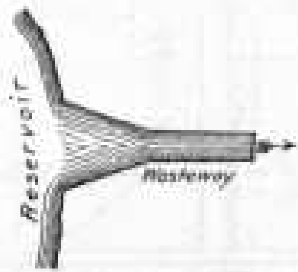

FIG. 9.—Flaring inlet to wasteway of reservoir.

The foregoing applies to reservoirs located in the beds of streams subject to floods. Under regulated inflows, such as those from springs, wells, and canals, the removal of the surplus water from a full reservoir is much less expensive. In such reservoirs this may be accomplished by the use of flash boards (fig. 8) or by laying a pipe of the requisite diameter through the embankment at flow line and extending it down the outer slope and far enough beyond so as to connect with an open ditch or ravine. The manner in which this may be done is indicated in figure 10.

SLOPE PROTECTION.

The outer slopes of farm reservoirs need little protection. It is only when the earth of which they are composed scours readily that a heavy rain is apt to form gutters which are not only very unsightly but may cause a breach. Even if the risk of a breach due to this cause is slight, it pays to expend some labor on the outer slopes if for no other reason than to improve their appearance. In the humid

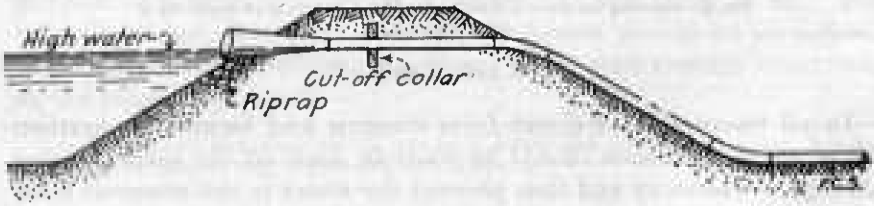

FIG. 10.—Waste pipe of small reservoir.

region an ugly bare embankment may be converted at little cost into an even, well-graded grassy slope. The sod, when once formed either by growing from seed or by transplanting, will prevent the erosive action of both rain and wind. When grass is unsuitable because of the dryness of the climate or other conditions, a layer of broken rock or coarse gravel and cobbles may be substituted.

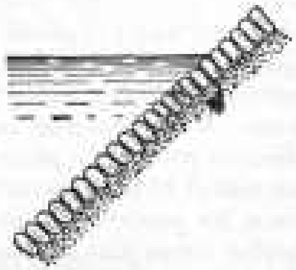

FIG. 11.—Stone and gravel riprap for slope protection.

The inner slopes of reservoirs need to be protected from the action of waves. Even small reservoirs in localities subject to high constant winds often are badly damaged from this cause unless the upper part of the inner slope is protected against such forces. Perhaps the most effective protection is secured by the use of a concrete paving surmounted by a parapet wall. This also is the most expensive. Where rock and coarse gravel are abundant near the site, the slope most exposed to the wind may be covered first with a layer of gravel and afterwards pitched with stone placed by hand as shown in the sketch (fig. 11). Less carefully placed rock is shown in figure 12. Brush may be used instead of the gravel and held down by rock or barbed wire, or by round timbers as shown in figure 13. In

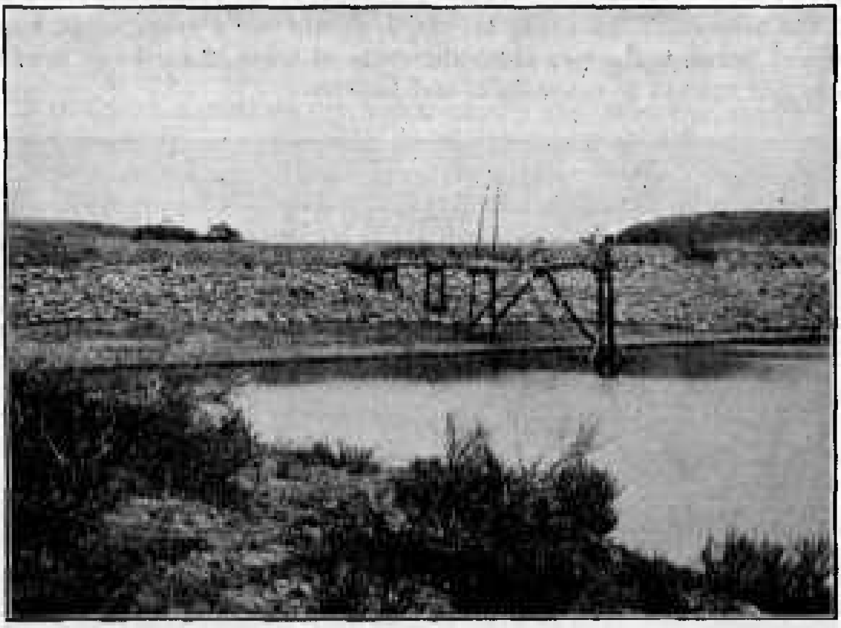

FIG. 12.—Rock paving on reservoir slope, near Casper, Wyo.

some cases a layer of cobblestones spread over a flat slope makes a fairly good protection.

Fences of various kinds also are used for preventing damage from wave action. The most inexpensive of these consists of a row of posts on which barbed wire is fastened at points about 2 inches apart. Back of the fence is packed straw, sagebrush, willows, coarse manure, or other material, which is held down by rock or barbed wire. Where lumber is cheap, a board fence (fig. 14) makes an effective protection while it lasts. Such boards of the requisite length are nailed to two borizontal joists anchored securely to the embankment by posts and deadmen and braced thorougbly. A floating lumber fence also has been used successfully. This consists of two planks placed on edge, one above the other which are allowed to rise and fall with the elevation of the water surface between wooden vertical guides which also act as posts.

In small reservoirs having low waves, erosion may be guarded against effectively by sodding the inner slope. For this purpose slough grass sod is preferable, as it will live under water. In laying such a lining, the slope is trimmed and a shallow trench or groove dug along the bottom to receive the first tier of sods. This precaution is necessary in order to avoid slippage when the water is turned in and the inner banks become saturated.

The cost of slope paving may be either greatly lessened or rendered unnecessary in time by planting a windbreak on the windward side of the reservoir. In doing so, there should be a space of at least 50 feet between the two since the roots of trees planted too near a reservoir are apt to cause leaks and failures.

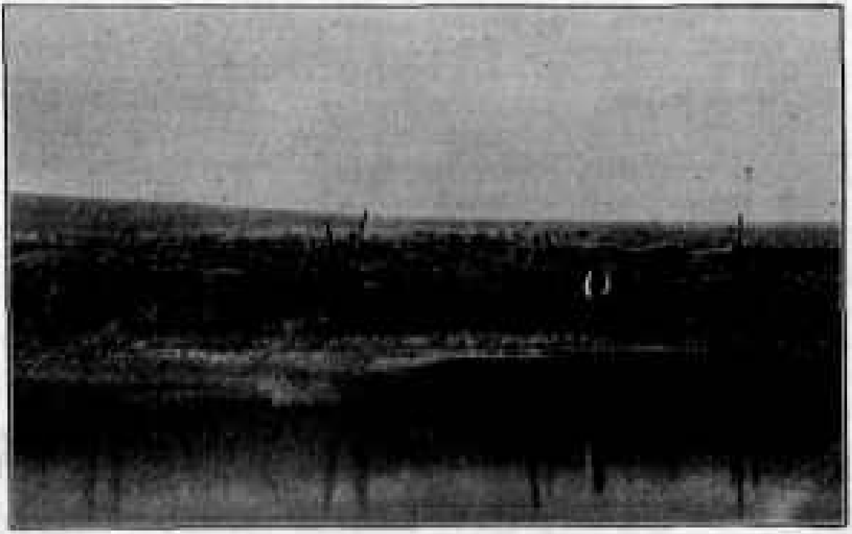

FIG. 13.—Reservoir slope protected by brush and timbers, Five Mile, Mont.

DIMENSIONS OF EMBANKMENTS.

The dimensions of embankments vary with the height, location, source of supply, and other conditions. The dikes which retain water in small shallow reservoirs fed by pumping plants need not be heavy. Their essential requirements are water-tightness and stability. Water slopes of 2 horizontal to 1 vertical and other slopes

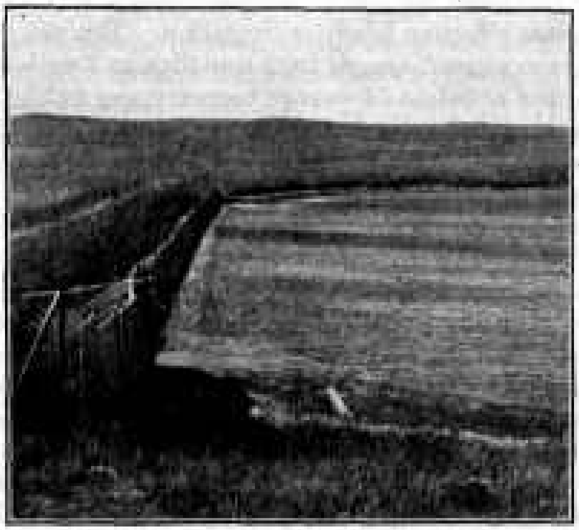

FIG. 14.—Reservoir protected by a board fence, Belle Fourche, S. Dak.

of 1½ to 1 with a suitable top width usually are sufficient. Heavier embankments are required when the reservoir is formed by damming the bed of a stream. In this type more or less uncertainty exists as to the flood flow of the stream, and to guard against overtopping the top width is increased and raised to a greater height above the flow line, i. e., the level of the surface of the water in the reservoir when full. The slopes likewise are somewhat flatter, the outer being about 2 to 1 while the inner may be the same, or else 2½ to 1.

TYPES OF FARM RESERVOIRS.

Farm reservoirs are rather difficult to classify for the reason that they are dependent on a number of unlike factors. The materials used, the methods of construction, locality, cost, source of water supply, and purpose which they are intended to serve, all exert more or less influence. Such being the governing conditions, any attempt to present types of such structures can not well be made without due consideration of the most influential factors. Thus an earthen reservoir planned and built to store water for irrigation may be unsuitable to provide water for stock. Similarly, the materials and methods of construction which may be used for a reservoir fed by a pumping

plant may not be well adapted to a reservoir located in the bed of a stream. Furthermore, a cost which is justifiable in the citrus orchards of southern California may be prohibitive in the Great Plains area.

RESERVOIRS USED WITH PUMPING PLANTS.

The following description is intended to be typical of a large number of small earthen reservoirs recently built in central California to store water furnished by small pumping plants and thus secure a larger and more effective head for irrigation. The net capacities of the reservoirs examined ranged from one-fifth to 7 acre-feet and the average cost per acre-foot of storage capacity was $97.[1]

The crops irrigated consisted mainly of alfalfa, fruit trees, grape vines, nursery stock, and gardens.

This type of farm reservoir in reality is an adjunct to a pumping plant and the proper relationship between the two should be studied carefully. The main purpose of both is to secure at the lowest rates, water from wells in sufficient quantities for successful irrigation. This can be done by installing a pumping plant of large enough capacity and dispensing with the reservoir. This, however, would be likely to entail a greater first cost for equipment, a higher annual rate for power, and a shorter operating time. Where there is no reservoir the capacity of the pumping plant would have to be increased at least 60 per cent and since electric current often is sold at a flat rate per horsepower based on the horsepower of the motor, it follows that a pumping plant driven by a 10-horsepower motor working 10 hours a day would cost twice as much for current as a 5-horsepower motor working 20 hours a day.

This type of reservoir usually is rectangular in form but it may be circular. The former is more apt to conform to fence lines, roads, fields, etc., is more readily laid out and built, but the latter requires less material and usually presents a better appearance. Before a site is selected it is well to find out the nature of the subsoil beneath it. This may be done by boring a hole with an auger or post hole digger, or by digging a pit to the required depth. If the examination shows the subsoil to be porous to considerable depths, the selection of another site may be advisable but if the porous material is confined to a single stratum it often is possible to lower the floor of the reservoir to a more impervious foundation by excavating the upper stratum. Such a course is followed often for the purpose of reducing the cost, as the most economical method of building an embankment around a reservoir is to take part of the material from within the site.

The site should be cleared of all brush, weeds, or other matter subject to decay, plowed and ridged and a trench dug along the center line of the embankment. One of the cheapest and best methods of puddling the material placed in the trench as well as that in the lower

[1] Report on farm reservoirs in Sacramento and San Joaquin valleys, Cal., by Wells A. Hutchins, assistant in irrigation economics, of the Office of Public Roads and Rural Engineering.

and central part of the embankment, provided the material is other than clay, is to fill the trench about two-thirds full of water and dump good puddling material into it. The puddled center core should be carried up into the embankment for some distance.

In building rectangular reservoirs the slopes may be kept fairly true to line by first setting up guide posts and small wire cables in the manner shown in fig. 15. The space between each set of poles is equal to the top width of the embankment when completed and the slopes of the cables correspond to the inner and outer slopes of the embankment. In circular embankments a template or portable form of guides may be used.

On a farm near Madera, Cal., there is a reservoir somewhat typical of this class. It is about 210 feet square, the banks are 7 feet high with slopes of 2 to 1 inside and 1½ to 1 outside, and the top width 3 feet. The reservoir covers 1 acre of land and has a capacity of 4.3 acre-feet. After the banks were formed by means of 4-horse Fresno scrapers, the bottom of the reservoir was covered with clay and puddled by cattle. The water is raised from a well by a 15-horsepower motor operating a 6-inch centrifugal pump, and discharged into the reservoir through a concrete pipe laid beneath the bank. There are two outlets, each consisting of a 14-inch concrete pipe controlled by an iron gate, which discharge into open ditches at some distance from the reservoir. The earthwork of the reservoir cost about $150, the structures $50, and the maintenance about $5 in three years. The pumping plant is operated continuously day and night for six months and supplies water for 240 acres of alfalfa. From 6 p. m. until 6 a. m. of the following day the well water is discharged into the reservoir and from 6 a. m. to 6 p. m. the irrigators draw from both sources of supply. In this way all irrigation is performed in the daytime, the labor and cost of irrigating is greatly reduced, while the plant is being operated continuously.

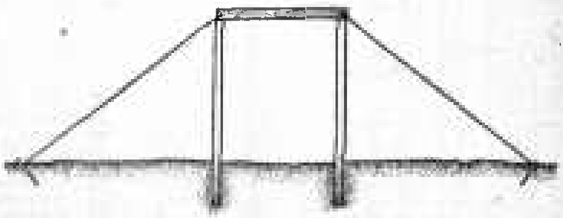

FIG. 15.—Guides for building earthen embankments.

For the past 25 years or so somewhat similar reservoirs have been in use in southwestern Kansas and in other parts of the Great Plains area. Before the day of the gas engine these formed a necessary adjunct of windmills, but in more recent times the gasoline engine has replaced the wind motor in many instances.

Table 3 [1] gives in summarized form considerable information pertaining to windmills and small earthen reservoirs located within the Garden City district of western Kansas.

[1] Irrigation from reservoirs in western Kansas and Oklahoma, by S. T. Harding and R. D. Robertson. (S. Doc. 1021, 3d sess., 62 Cong.)

TABLE 3.—*Data pertaining to windmills which discharge well water into small reservoirs in the Garden City district of western Kansas.*

Number of plant.	Area.	Crops.[1]	Number of trees.	Size of mill.	Cost of plant.	Size of reservoir.	Cost of reservoir.	Annual maintenance.	Value of crops.
	Acres.			*Feet.*		*Feet.*			
1	4.0	G and C	100	10; 12	$200	100 by 30 by 2	$20	$4.00	$300
2	20.0	G; SB; A	400	25; 10; 10	1,000	100 by 200 by 4	150	2.50	1,500
3	6.0	G; F; SB	700	12	200	75 by 100 by 5	20	.50	1,200
4	4.0	A and SB		12	200	75 by 100 by 5	20	.50	250
5	25.0	A	800	[2] 3-12	360	90 by 185 by 3.5	100	30.00	1,600
6	8.0	A		12	120	150 by 60 by 3	50	10.00	350
7	8.0	G; SP; C		12	150	100 by 3, round	45	3.65	800
8	2.5	G	100	8	55	30 by 100 by 3	10	4.00	125
9	4.0	G; F; Fl	300	8; 10	85	30 by 35 by 3.5	15	2.00	200
10	3.0	G	100	10	102	20 by 70 by 2	15	1.50	500
11	2.0	G; F	40	10	75	30 by 50 by 2	12		150
12	8.0	G; F	800	8; 12	185	85 by 110 by 3	40	11.00	550
13	5.0	B; F; G	125	10	100	50 by 100 by 2.5	20	2.00	500
14	1.5	B; F; G	200	8	92	24 by 24 by 2	10	.75	400
15	2.5	G	100	8; 10	70	30 by 30 by 3	10		300
16	2.0	G and F	800	14	175	75 by 75 by 3.5	25	5.00	
17	7.0	G and SB	150	2-12	230	125 by 125 by 3	40	30.00	200
18	2.0	G	116	8	70	40 by 40 by 2.5	15	.50	150
19	1.0	G	200	8	12	35 by 35 by 2	10	3.00	200
20	5.0	B; F; G	800	2-8	150	50 by 50 by 2.5	50	1.50	300
21	4.0	G and F	3,000	12	103	75 by 75 by 2.5	15	.50	500
22	4.0	SP		10	93	30 by 70 by 3	15	.50	250
23	.25	C	30	8	62	50 by 50 by 3	25	.50	100
24	3.0	G and F	300	10	91	25 by 25 by 2	10	1.50	500
25	10.0	G; A; F	1,000	10; 12	230	100 by 110 by 3	30	1.50	750
26	3.0	B; F; G	260	8; 8	90	30 by 50 by 3	13	1.35	500
27	4.0	G and F	375	12	128	50 by 30 by 3	12	15.00	500
28	12.0	G and F	500	2-12	225	100 by 500 by 3	50		500
29	10.0	G and F	150	2-12	193	75 by 100 by 2.5	15		1,500
30	5.0	B; F; G	100	12	72	60 by 60 by 4	20	5.00	200
31	2.5	B; F; G	100	2-8	164	40 by 50 by 2	10	.75	200
32	2.5	B; F; G	75	8	60	60 by 60 by 3	20	5.00	200
33	4.0	G		12	85	2.5 by 50 diam	40	7.00	200
34	4.0	G	300	12; 8; 8	250	100 y 100 by 3	50	12.00	300
35	2.0	G	800	8	75	20 by 25 by 2	10	None.	100
36	10.0	T	2,000	2-12	200	250 by 100 by 3	75		700
37	2.5	G	150	10	75	20 by 111 by 2.5	10	5.00	175

[1] The following abbreviations are used: A, alfalfa; B, berries; C, cantaloupe; F, fruit; Fl, flowers; G, garden; SB, sugar beets; SP, sweet potatoes; St, strawberries; T, trees.
[2] This indicates three 12-foot mills. Other similar figures indicate number of mills of the size given.

The customary practice in building these reservoirs is to locate them on the highest suitable ground adjacent to the pumping plant. The material for the embankments is taken from the inside, the space being plowed first and then scraped. To secure earth from the outside of the reservoir would remove the upper layer of soil and this in turn would lessen the yields of crops. Forming the banks from material taken from the inside results in lowering the bottom considerably below the natural ground surface and in this way lessens the effective holding capacity of the reservoir since the water in the bottom can not be drawn off and used in irrigation. On the other hand, there is a decided advantage in having this extra storage to stock with suitable kinds of fish.

The inner slope first is smoothed by hand and then sodded with slough grass from bottom to top, care being taken to lay the first row of sods in a groove or V-trench at the bottom to prevent the sods from slipping when water is first pumped into the reservoir and the banks become soaked.

Figure 16 shows a reservoir of this type in which the water is raised from a well by a small pumping plant.

RESERVOIRS BUILT IN BEDS OF STREAMS.

Under this heading are grouped reservoirs of a somewhat larger capacity than those previously considered. The reservoirs of this type are built in the beds of streams or other depressions and are used mainly for irrigation purposes. The dam may be of earth, loose rock, timber, concrete, or masonry, or combinations of two or more of these. However, since on the large majority of sites earth is the most abundant and cheapest material available, it has been used chiefly. The percentage of failures of dams of this type has been large. The main causes have been (1) faulty and inadequate wasteways, (2) porous earthen embankments not properly compacted, and (3) insecure foundations.

FIG. 16.—Pumping plant with earth reservoir, Garden City, Kans.

When the location for the dam has been decided upon a careful examination of the foundation should be made. Test pits should be sunk at intervals across the stream bed or depression, and if rock or other impervious material is found near the surface, the more porous top covering should be removed and the foundation laid on the impervious substratum. In any event, all shrubbery, sod, and decayed vegetable matter should be cleared away before the dam is begun. In the better class of such dams a narrow trench is dug beneath the center of the embankment down to bedrock or other good material and a wall of concrete, known as a rim core wall, is built therein. This wall projects above the surface and serves a purpose similar to a tongue in grooved-and-tongued lumber joints. A clay puddle may be substituted where a concrete core wall around the rim would prove too expensive. In this case a much wider trench should be dug, filled with the best material available, and carefully puddled and rammed.

In building a reservoir embankment of earth many farmers and not a few engineers fail to understand the difference between an embankment capable of withstanding a load such as is placed upon it by the passage of a locomotive and one compact and stable enough to hold water. In highway and railroad fills little, if any, attention is paid to packing the materials, but in the case of earth fills to retain water, packing is a necessity. Experience has shown that one of the best ways to pack ordinary dirt which does not contain too much clay is to dump it into water and let nature do the packing. When this method is not feasible the earth should be placed on the embankment in thin layers and each layer moistened and rolled or otherwise compacted. In some cases the earth can be moistened before it is removed from its natural site.

As has been stated, a frequent cause of failure of such dams is faulty wasteways. The dams, being built for the most part in the

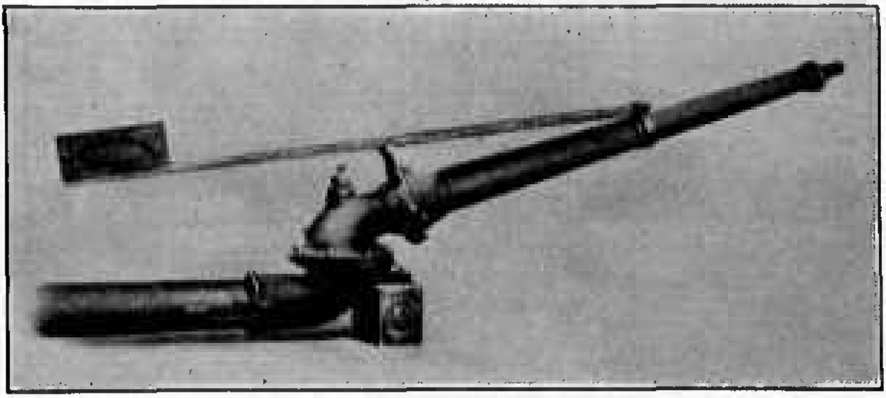

FIG. 17.—Double-jointed, ball-bearing giant used in hydraulic construction.

beds of streams and in the direct line of flood flow, are subjected at times to high water which may carry floating driftwood or other debris. The overflow dam is designed to withstand such severe tests, but the dam considered here is not of this type. It is intended only to impound water to a certain safe height and to by-pass all surplus waters through the wasteway. This throws a heavy burden upon this structure in times of flood, and it should be of such strength and capacity as to perform its part without danger to the dam. In making provision for a wasteway it should be borne in mind that a flood may occur when the reservoir is full, so that the entire flow of the stream must pass through the wasteway. Consideration also should be given to obstructions to the flow of water caused by driftwood and clogging of fish screens.

Such features of this type of reservoir as inlet and outlet pipes, slope protection and the like have been discussed in the first part of this bulletin.

In the early days of mining in California, some one evolved the idea of washing down the gold-bearing sand by means of powerful streams of water directed against the banks and hillsides. This practice has been improved and extended and now is a commonly used method of building earthen embankments and of loosening and transferring earthy material for other purposes. In making use of this method an ample supply of water is necessary. What is called the "cutting stream" is under high pressure from 60 to 100 pounds per square inch. The pressure may be obtained by gravity fall or by pumping, and the water is conveyed to the material to be excavated in a pressure pipe of suitable diameter. The end of the pressure pipe terminates in a giant (fig. 17) from which a stream is directed against the bank

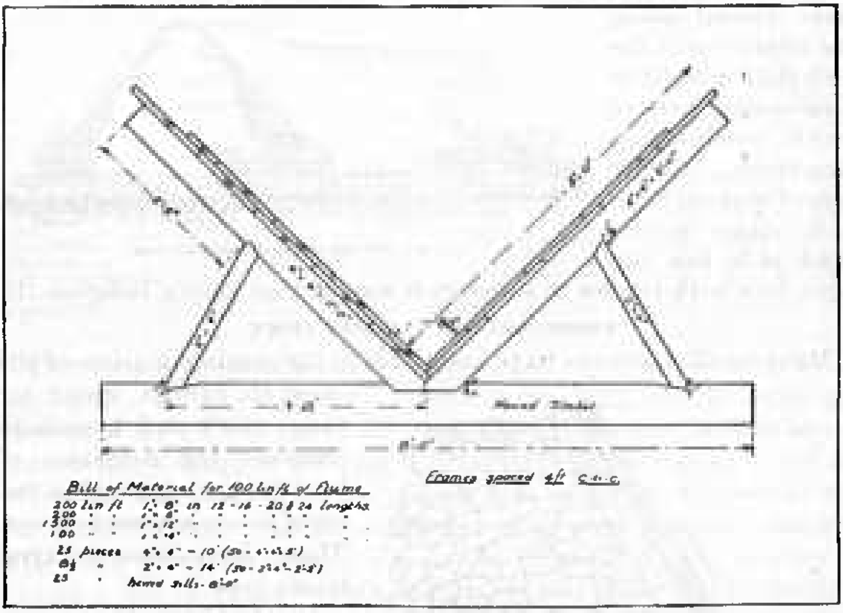

FIG. 18.—V-shaped flume used in sluicing.

of dirt. A larger stream of water, but under little or no pressure, then is added to the former stream to carry the material loosened by the giant into a flume or pipe in which it is transported to the dam. Figures 18 and 19 show two forms of wooden flumes used for this purpose. The grade on which they are laid should be as steep as practicable and never less than about 5 per cent. Under favorable conditions material can be placed in a dam by this process at a lower cost per cubic yard than by the use of teams and scrapers or teams and wagons. Such embankments are also more compact and water-tight than those built by ordinary methods.

Dams built of loose rock without any cementing material usually have sufficient weight to withstand water pressure but the ease with

which water can percolate through such structures renders them unsuitable to retain water. This defect is overcome in various ways of which two will be described here briefly. The usual way of making loose rock dams water-tight is to place earth in front in the manner indicated in figure 20. (See p. 38, pt. 2, O. E. S. Bul. 249.)

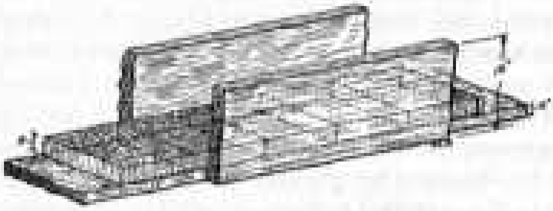

FIG. 19.—A rectangular flume used in sluicing.

The same care should be taken in placing this earth as has been recommended for earthen dams proper and the cut-off wall of concrete placed along the upper toe of the rock slope usually is a necessary part of such combination structures. Another way of making loose rock dams water-tight is to line the front face with timber in some such way as that shown in figure 21.[1]

FIG. 20.—Section of typical rock-fill dam.

RESERVOIRS FOR WATERING STOCK.

Many small reservoirs have been built in the grazing districts of the West to furnish water for range stock and household purposes, the irrigation of land from such supplies being of secondary importance. These have been grouped under type 3.

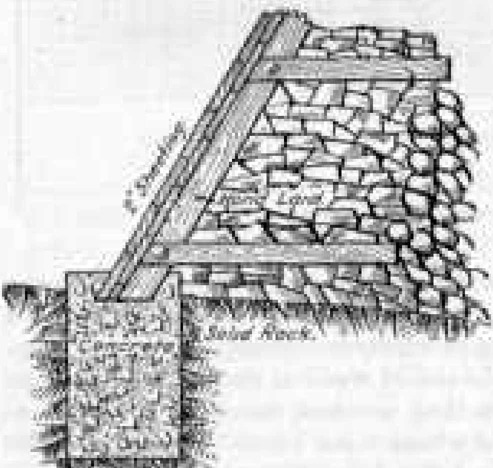

FIG. 21.—Showing method commonly used for facing rock-fill dam with timber.

In the Great Plains area and more particularly in the eastern portions of Wyoming and Montana and the western portions of the Dakotas, there is little stream flow during the greater part of the year and the well water often is so impregnated with mineral salts as to be unfit for drinking purposes. On the other hand, the native grasses are abundant and nutritious but the cattle and sheep which graze thereon are not permitted to feed beyond

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[1] The storage of water for irrigation purposes, by Samuel Fortier and F. L. Bixby, U. S. Dept. Agr. Office of Experiment Stations Bul. 249, pt. 1.

easy reach of the nearest water hole. Thus without the use of reservoirs or other means of providing water, the public range can be only partially utilized and too often the big stock companies, in acquiring possession of the land bordering springs and streams, become the sole beneficiaries of the use of such lands.

Other reservoirs of this class have been built by transportation companies in order to provide water for cattle and sheep en route from the range to the nearest railway station. The following table gives some data pertaining to a few of these which are typical of a large number that were built by the Chicago and Northwestern Railway Company.[1]

TABLE 4.—*Dimensions, capacity, and cost of certain dams.*

Name of dam.	Height.	Length.	Capacity.		Cost.	
					Total.	Per acre-foot.
	Feet.	*Feet.*	*Gallons.*	*Acre-feet.*		
Powder River	24.1	200	3,770,800	11.5	$782.00	$68.60
East Woolton	16.0	207	4,762,500	14.6	550.00	37.70
Forks	16.0	218	4,500,000	13.8	470.00	34.08
Lusk	9.0	150	2,175,000	6.6	86.00	13.03
Duck Creek	12.5	200	4,000,000	12.3	474.00	38.84
Dry Creek	16.0	352	2,400,000	7.4	371.00	50.21
New Indian Springs	15.0	230	4,300,000	13.2	427.00	32.35
New Bull Creek	16.0	400	4,000,000	12.2	719.00	59.00
Crouse Creek	16.8	240	3,052,700	9.3	673.00	72.40

The dams for reservoirs of this type are of earth built for the most part in the beds of streams. Before the embankment is begun the surface of the ground under the entire base of the dam, as well as the borrow pit, is stripped for a depth of at least 6 inches so as to get rid of all sod and other light, porous material which would prevent the earth in the dam from settling in a solid and compact manner. After the ground has been so stripped and before the grading is begun, a trench 12 feet wide and not less than 18 inches in depth is dug the entire length of the proposed dam. The edge of this trench from the upstream side is not less than 3 or more than 10 feet inside the toe of the inner slope. This trench is dug for the purpose of breaking the seam that otherwise might exist between the natural ground and the constructed dam.

The dam then is built in the usual way by placing the material in uniform layers under the whole base of the dam. Figure 22 shows the standard dimensions used in embankments and the position of the intercepting trench. It will be noted from this sketch that the flow line of the wasteway is 5 feet below the top of the embankment.

Wherever possible, a natural wasteway was utilized in direct line with the stream channel and the dam located to one side so as not to be subjected to the direct force of the stream.

[1] Small reservoirs in Wyoming, Montana and South Dakota, by F. C. Herrmann. U. S. Dept. Agr., Office of Experiment Stations Bul. 179.

To protect the embankment from waves produced by the high winds of the open prairies, the inner slope may be covered with rock, brush and rock, or other material. A common kind of protection consists of sheet piling formed of inch boards 10 inches wide and 8 feet long. Each board is driven into the embankment at the edge of the water of a full reservoir to a depth of 3 feet and then nailed to two horizontal ties of 1 by 10 inch boards. These latter are braced to dead men buried in the dam in the manner shown in figure 22.

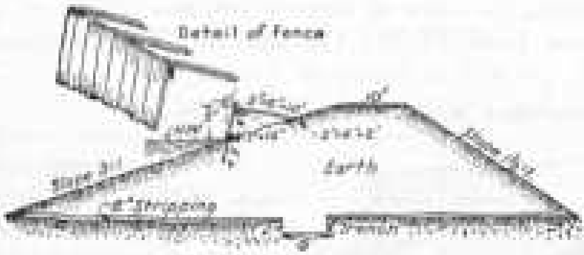

FIG. 22.—Cross section of earth dam showing intersecting trench and wave fence.

Smaller earthen reservoirs or "settling basins" for the watering of stock are common in Imperial Valley, Cal. These are usually rectangular in form, 20 by 30 feet being a common size and about 4 feet deep. To keep out the stock they are fenced with the exception of a drinking place about 6 feet long, which is cribbed. The cribbing consists of two 12-inch planks spaced 6 inches apart with the intervening space filled with sand. Figure 23 illustrates this cheap method of furnishing water for stock. In recent years a more costly equipment to provide water for domestic purposes as well as stock has been introduced in the valley. Such a plant is shown in figure 24 and comprises a reservoir lined with concrete into which the muddy water from the irrigation canal is diverted by the supply ditch shown in the foreground, a pumping plant, and an elevated metal tank into which the settled water from the reservoir is pumped. The reservoir is 14 by 18 feet in area, 7 feet deep and has a removable cover in order that the silt may be cleaned out periodically. The walls are 6 inches thick throughout and the bottom 3 inches thick. The tank has a capacity of 3,750 gallons and this quantity of water serves 100 head of cattle and also provides for all domestic uses for a period of three days. A wooden derrick supports the tank at an elevation of 27 feet above the ground and pipes of black iron 1¼ inches in diameter distribute the water contained in the tank to two troughs in the corrals and to two other troughs in the fields. A 3-horsepower gas engine and a 4-inch plunger pump lift the water from the reservoir into the tank. The various items of cost of this plant are as follows: [1]

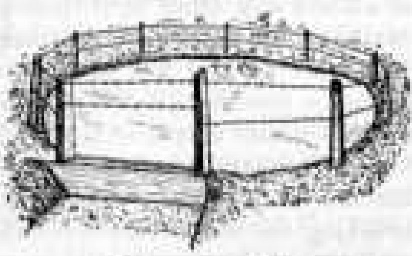

FIG. 23.—Settling basin for stock water.

[1] From report of F. J. Veihmeyer, assistant irrigation engineer, Office of Public Roads and Rural Engineering.

Concrete reservoir, including excavation	$112.00
Reservoir roof	20.00
Derrick	103.00
Tank	75.00
Engine and pump	240.00
Piping and extras	250.00
Total	$800.00

RESERVOIRS IN THE ATLANTIC COAST STATES.

Type 4 includes small earthen reservoirs in the Atlantic Coast States and throughout the humid region generally. Three kinds are discussed briefly. The smallest of these may be represented by what one finds in the dairy districts of New York State. The primary object of storing water in this part of the country is to provide ice for dairies and household use. A pond 125 by 125 feet has a free

FIG. 24.—Settling reservoir, pump, and tank in Imperial Valley, Cal.

cutting ice surface of about 100 by 100 feet and one crop of ice from this surface, even though it be but 4 inches thick, fills an ice house 18 by 18 by 10 feet deep, having a capacity of 80 tons. Of late years, the increasing extent and importance of truck crops and the damage inflicted on such crops by summer droughts have led many to use their ice ponds for irrigation in summer and for ice in winter, thus securing a double service from this cheap farm reservoir.

Figure 1 (p. 4) shows in outline a homestead near which is to be found a small pond fed from a spring, and an irrigated garden. In building this pond advantage is taken of a stone fence which encircles the lower two sides. The weight of the rock serves to strengthen the bank and the wall prevents the dirt from being washed away. Before the base of the banks are formed, the site should be plowed shallow and the sods removed. It is then plowed as deep as possible and the surface moistened, after which earth is scraped from the upper end to form the banks around the lower end. In such work

it is seldom convenient to place the dirt in layers and to sprinkle each layer. A cheaper and equally effective method is to run water into the pit from which the dirt is scraped at the close of each day. By next morning the water will be absorbed unless much clay is present and the dirt not only will pack well but a larger amount can be taken out on the slip at each trip.

A pond of the size shown will hold, if filled $3\frac{1}{2}$ feet deep, enough water to irrigate about 6 acres to an average depth of 2 inches or 4 acres to a depth of 3 inches. If a 6-inch pipe is laid from the pond to the truck crops it will enable the farmer to utilize in irrigating crops all the water the pond holds in one day of 12 working hours. If the water in the pond is carried in a 4-inch pipe, it will take nearly 3 days of 12 hours each to empty the reservoir. A durable pipe for such reservoir outlets frequently can be purchased for little more than the price of drain tile. Reference is here made to rejected sewer pipe. Such pipe is unsuited to the rigid requirements of city sewers but may serve the purpose of a farmer as well as a more costly pipe.

In cases where the spring or other source of water supply is below rather than above the irrigated tract, the flow may be stored in a reservoir similar to the one just described and then pumped to the tract by a pump driven by a small engine or motor. This arrangement is shown in figure 2 (p. 5).

While the hillside reservoir from which the stored water flows by gravity costs less to maintain, it is the most expensive to construct. Less expensive storage as regards first cost can often be secured by scooping out muck beds in a natural sump. These saucer-shaped ponds are used to provide water for various farm purposes, of which the irrigation of cranberries may be mentioned. In the latter a special pump of low lift and fairly large capacity is used to raise the water from the pond to flood the beds.

The third kind to be considered under type 4 is more frequently met in the South Atlantic States. Swampy or over-flowed areas are frequently converted into shallow reservoirs by the building of an earthen dike across the outlet. These dikes are built in dry periods with teams and scrapers. If the material is too wet or unstable for teams to work, the dike is built by laborers using shovels. In so far as practicable, the base of the dikes should be cleared of all brush and coarse grass, and plowed. The low banks are then formed in the usual way, the upper, or water, slope being protected with brush and rock or brush and wire wherever there is any risk of scouring by wave action. The most common, and perhaps the best, outlet for a reservoir of this kind consists of a wooden flume of cypress lumber controlled by flashboards of the same kind of wood. The dike or dam often serves as a roadway also. Under this dual use

it has sufficient top width for the passage of teams. The water stored in these shallow reservoirs may be conducted in flumes and pipes to irrigate land or to develop power. In rarer instances it is pumped to higher levels for irrigation purposes.

RESERVOIRS IN HUMID REGIONS.

In this type are included reservoirs formed by building dams at favorable sites across the beds of brooks, creeks, or other small streams throughout the humid region. Some of the kinds of dams described under types 2 and 3 are suitable for type 5. This is especially true of the combination earth and rock dam referred to on page 24.

In recent years a demand has arisen for a more stable and permanent dam than those outlined previously. This is due mainly to the more extended application of power to farm purposes and to the cheapness of cement concrete, both plain and reinforced. However, in attempting to present a structure of this kind which will be typical one is face to face with the difficulty of making it fit a large number of unlike sites, conditions, and requirements. For this reason little more than suggestions can be offered in the form of tentative designs of which two are given.

One of these may be used to good advantage in stream beds having bedrock on the bottom and sides, as sketched in the profile (fig. 25). In such favorable locations a concrete dam can be built cheaply with the use of little steel for reinforcing, as the greater part of the concrete is in compression. According to the profile, the left bank of the creek is quite steep, and the dam can be built into the rocky face without trouble. On the other side of the creek the slope is less steep, and a short length of wall or abutment of the gravity type of masonry dam is introduced in order to confine the dam proper to four arches. The number and length of span of these arches, of course, will depend on the width of the channel, the height to which the water is to be raised, and other conditions. In the tentative design submitted (fig. 25) the water is to be raised 12 feet above the bed of the creek, but the structure is made strong enough to resist a flood flow of 3 feet over the crest of the dam, making a total depth of water of 15 feet. The bed width of the channel is divided into four parts with three buttresses of the form shown. These buttresses are embedded in the rock in order to prevent sliding, and steel reinforcing rods extend from 3 feet below the bed of the creek up through the entire height of each buttress to prevent overturning and also to relieve the concrete of tensile strain. Each of the four arch rings and the gravity section likewise are embedded in the rock at the bottom and on the left bank to afford greater strength and to prevent leaks.

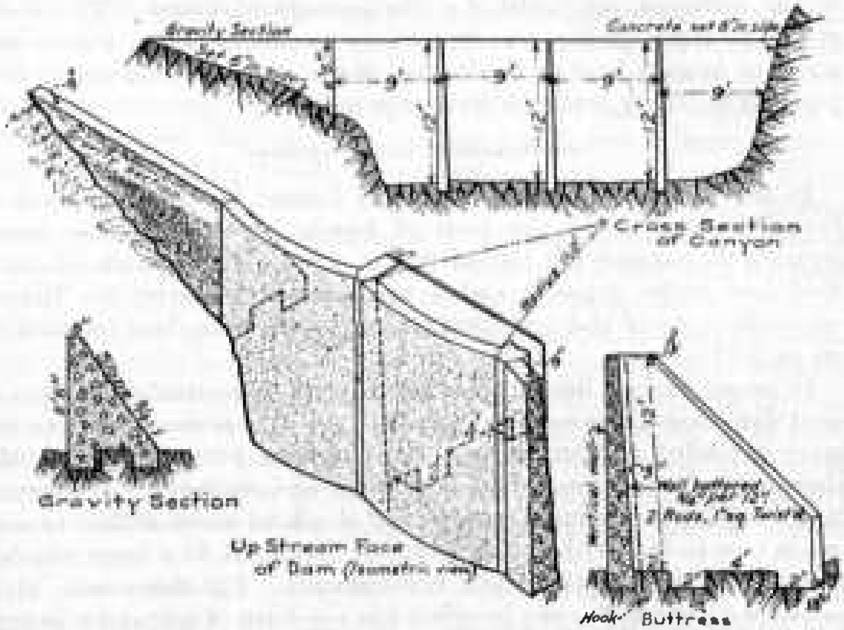

FIG. 25.—Outline of concrete dam for rocky stream bed.

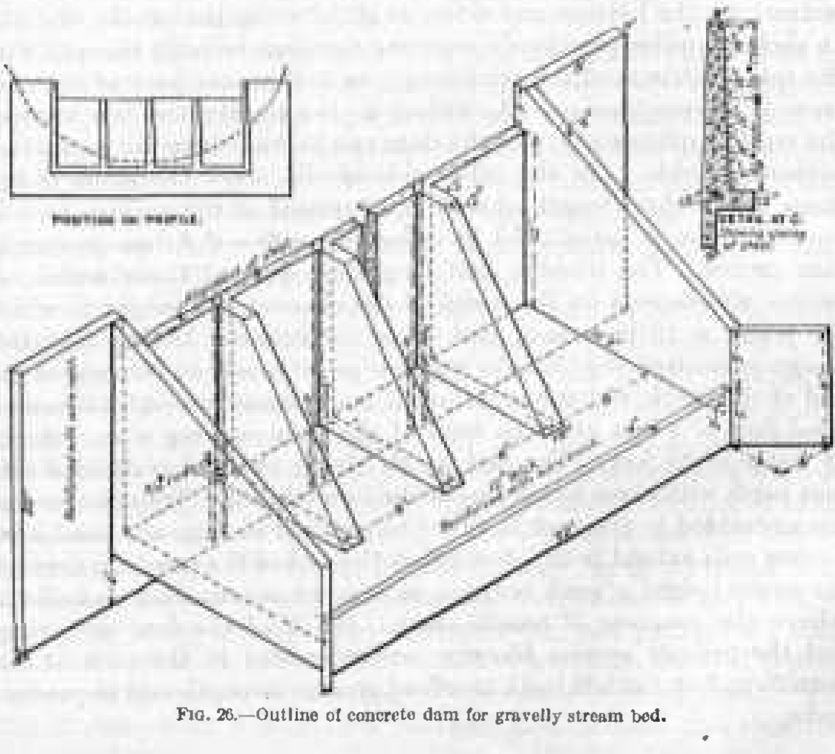

FIG. 26.—Outline of concrete dam for gravelly stream bed.

In the other tentative design shown in figure 26 bedrock is too far below the surface to be of service as an anchorage and water-tight connection, and it is necessary to modify the design in such a way as to adapt it to another set of conditions. In this case the chief thing to consider, apart from stability and permanence, is the likelihood of water escaping either under or at one side of the structure. Experience has shown that when a small stream finds its way under or to the side of a dam it is liable to erode the finer material and thus enlarge the opening until a large volume of water passes through and the dam is wrecked.

To safeguard the structure against a possible failure of this kind a cut-off wall of concrete not only extends far below the bed of the creek but also into the banks of each side (fig. 26). This wall is supported by an abutment on each side and also by three buttresses. Such a dam also has to be safeguarded against the action of water falling over the crest upon the earth and gravel in the bed of the stream. This is done by extending the floor and sides of the dam sufficiently far downstream and by riprapping the channel beyond the lower end of the structure. In this design the depth of water is to be 12 feet, with an allowance of 3 feet over the crest during flood periods. The concrete is reinforced throughout, and it is believed every part of the structure possesses ample strength to withstand all ordinary tests.

CONCRETE-LINED RESERVOIRS.

Earthen reservoirs lined with concrete constitute another type. In form they may be either rectangular or circular. A circular reservoir (fig. 27) lined with concrete, having a diameter of 134 feet at the bottom, a depth of 8 feet, and a capacity of 2 acre-feet, or 651,658 United States gallons is somewhat similar in design to one built under the supervision of the Office of Public Roads and Rural Engineering at Fort Collins, Colo.[1] The earthwork of such a structure does not differ much from other earthen reservoirs already described. The same care is exercised in securing a water-tight connection between the natural surface and the fill and in making the latter stable and impervious. Further precautions are necessary, however, in order to prevent damage by settlement and frost. If the reservoir is formed partly in excavation and partly in fill, it is difficult to treat each class of material in such a way that both will be equally stable and impervious. If the material in the fill, for instance, settles more than the natural earth, the concrete lining is apt to be ruptured along the division line. Not only uneven settlement in different parts of the earth embankment but settlement in any one part tends to rupture or otherwise damage concrete lining. To safeguard the structure against such damage it is recommended that the completed

[1] Hydraulic laboratory for irrigation, Fort Collins, Colo., by V. M. Cone, Office of Public Roads and Rural Engineering, in Engineering News, vol. 70, No. 14.

earthwork be thoroughly soaked before the lining is laid. By keeping the reservoir full of water for an entire year both the natural and made surfaces have a chance to settle. The water is then withdrawn and the surface allowed to become partly dry when it is carefully tamped, leveled, and smoothed. Before the final tamping is done a layer of coarse gravel is spread over the surface and driven flush with the grade with tamping bars.

In parts of the country having cold winter climates the damage to the lining caused by frost upheaval can be guarded against in at

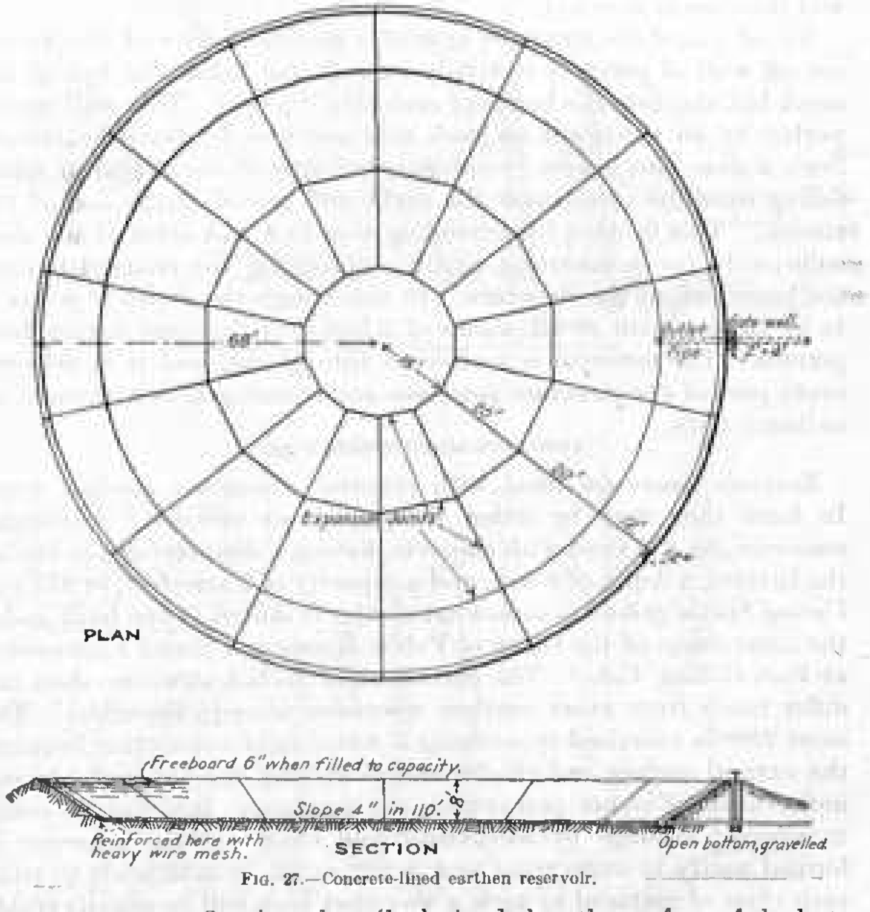

FIG. 27.—Concrete-lined earthen reservoir.

least two ways. One is to lay tile drains below the surface of the bottom of the reservoir and the other is to tamp in sufficient coarse gravel and sand in both the bottom and sides to provide for ample drainage.

A concrete suitable for lining should contain an ample percentage of good cement in order to make it water-tight. A mixture of 1 part by volume of cement, 2 parts of sand, and 4 parts of gravel or broken rock is recommended. A measured volume of sand is dumped on the mixing platform, half as much cement is added to it and both

ingredients are mixed dry until the mixture is of one color. It is then moistened and worked into a soft mortar, and the rock or gravel, having been previously moistened, is added. The mortar and rock or gravel then are turned over with shovels at least twice or until the entire mass is thoroughly mixed. The concrete should be sufficiently moist at this stage so that when shoveled into a wheelbarrow or other means of conveyance it will assume a water level on top. At the same time it should not be so wet as to flow readily.

In placing concrete on the slopes, forms are dispensed with other than a couple of guide planks having a depth equal to the thickness of the lining and spaced as indicated in figure 27. It is possible to place wet mortar on a slope of 1 horizontal to 1 vertical, but a better job usually can be done if the slope is 1¼ or 1½ horizontal to 1 vertical. The slope as given in figure 27 is 1½ to 1. There also should be a slope of several inches to the hundred feet across the bottom of the reservoir so that water may be drained to the outlet.

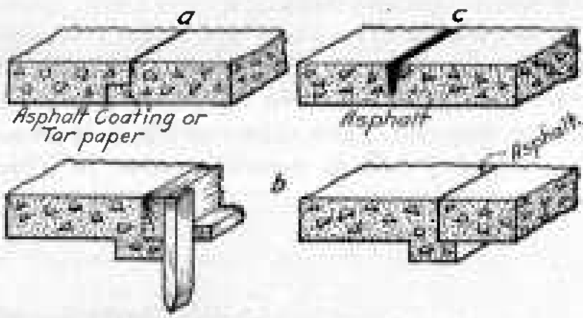

FIG. 28.—Showing several joints used in concrete lining.

The thickness of the lining needed depends upon the severity of the climate, the care and skill used in preparing the foundation, the character of the concrete and other factors. Another consideration is the desirability of keeping the first cost of such structures as low as possible consistent with efficiency and durability. Generally speaking, a lining 2 inches thick will suffice in a climate with little frost, whereas in colder climates a 4-inch thickness may be needed. In the reservoir herein outlined a 3-inch lining is used. In lining reservoirs, it is not necessary to use a greater thickness in the bottom. The parts that usually show defects in course of time are to be found around the top rim or at the junction of the bottom and the side slopes. The former can be strengthened by a coping as shown and the other by light reinforcing and a slightly greater thickness of concrete.

Various kinds of joints are used to prevent cracks in concrete lining. Three of these are sketched in figure 28. One of these (fig. 28a) is merely the carpenter's ship lap or half timber joint applied to concrete. The same may be said of figure 28b, with this difference, however, that the latter is strengthened by an extra

block of concrete. In thin linings this is a necessity in this kind of joint. In the third kind (fig. 28c) the joint does not extend through the lining. A thin strip of oiled wood is inserted in the joint, and when the concrete has set the wood is removed and the space is filled with hot asphalt of such a character that it will not crack when dropped in ice water.

RESERVOIRS BUILT OF COBBLESTONES.

Many small reservoirs have been built in southern California to store water pumped from wells over night for use in irrigation the following day. In the Pomona Valley, which includes an area of valley land comprising something like 67 square miles, of which about one-third is irrigated, there were in 1912 over 50 of these reservoirs owned and operated by individual orchardists or by small groups of orchardists cooperatively. In the preparation of much of the land for citrus orchards on the benches of this valley large quantities of cobblestones are removed and dumped into ravines or piled up in long rectangular walls. Years ago some one conceived the idea of making use of this rock to give stability to reservoir walls, and out of this conception has been developed a more or less distinct type of farm reservoir. This type consists in the main of a wall of cobblestone masonry laid in cement mortar in which a small

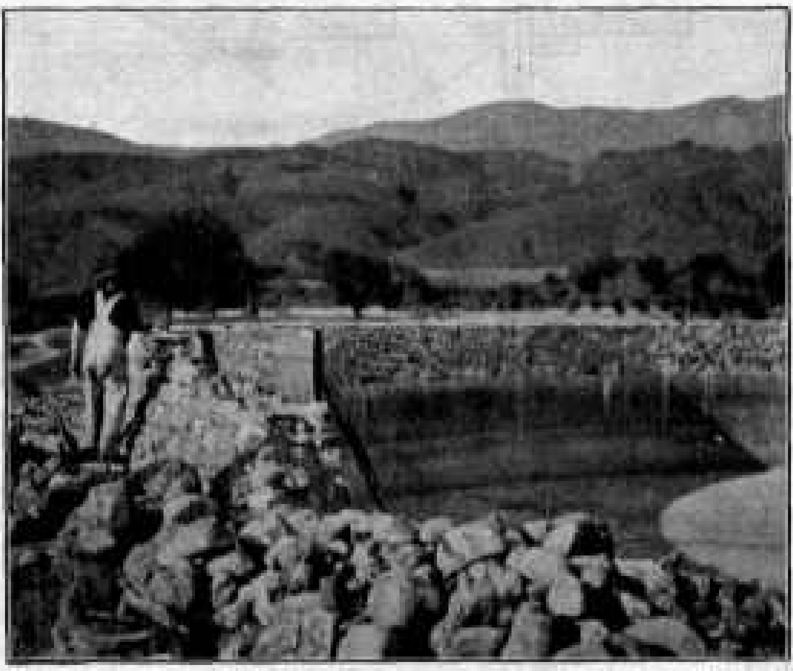

FIG. 29.—Showing construction of cobblestone masonry wall.

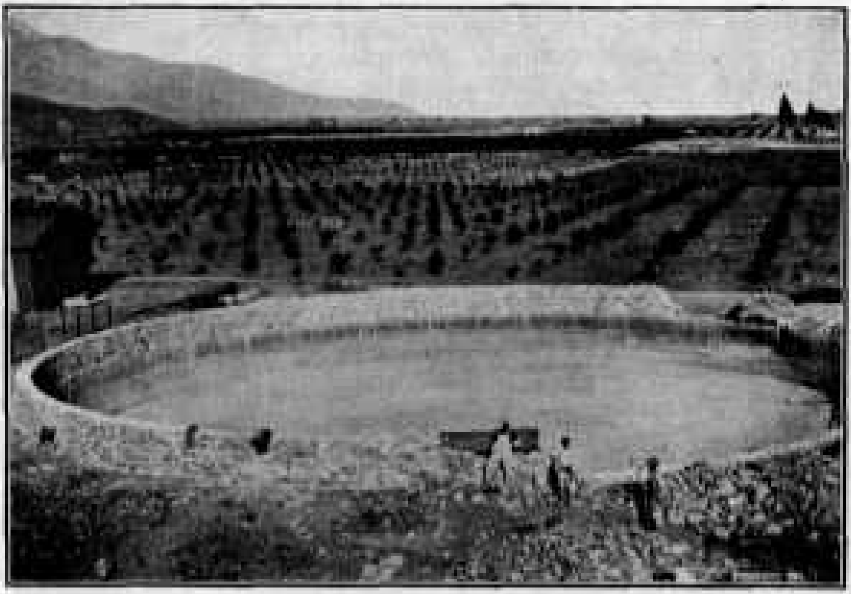

FIG. 30.—Showing cobblestone wall of reservoir nearing completion.

amount of lime is incorporated, a concrete floor, and an earth embankment around the exterior.

From an engineering standpoint the crucial tests of a reservoir may be said to be such features as efficiency, durability, first cost, and maintenance. When a reservoir having its walls composed largely of cobblestones is compared with a reinforced concrete tank of like capacity in respect to the tests named, in all probability the latter would be found to be the more economical type of construction. Notwithstanding this fact reservoirs composed largely of cobblestones possess a number of advantages from the point of view of the farmer and orchardist. Such reservoirs can be built for the most part by mechanics and farm laborers out of materials on the farm with little or no expense for engineering surveys, specifications, or supervision.

This type of reservoir is built either on or near the surface of the highest part of the tract or tracts to be irrigated in order that the water which it is designed to hold may flow by gravity to all parts of the orchard.[1] For this and other reasons the earth foundation should be made secure against settlement. A good plan is first to level off the site, build a levee around it, and fill the inclosure with water to a depth of 12 or more inches, allowing the water to remain at this depth until the soil and subsoil are well soaked. The site then is

[1] The use of underground water at Pomona, Cal., by C. E. Tait, U. S. Dept. of Agr., Office of Experiment Stations, Bul. 236.

allowed to dry out partially and when still moist is well tamped, the low places filled in, the entire surface covered with coarse gravel, sprinkled, and again tamped. The inlet and outlet pipes are then laid on beds of concrete, after which the exterior wall may be begun. In a reservoir recently completed at Claremont, Cal., having an inside diameter of 150 feet and a depth of 10 feet, the thickness of the wall was 3½ feet at the bottom and 1½ feet at the top, with a batter on the inside. The cobblestones forming the exterior wall were laid in cement mortar composed of one part cement, one-fourth part lime, and four parts sand. The inside of the wall was lined with a coating of cement plaster and the floor consisted of a 5-inch layer of concrete.

FIG. 31.—Cobblestone reservoir completed and filled.

The pumping plant which feeds this reservoir delivers about 450 gallons per minute, and a head of nearly double this quantity is withdrawn from the reservoir during daylight hours to irrigate 183 acres of orange and lemon orchards. Figures 29 and 30 show the manner in which the walls are built and figure 31 the general appearance of a reservoir of this type when completed and filled with water.

OTHER TYPES.

Water for irrigation and other purposes is also stored in tanks of various kinds. These consist of wooden staves held together by steel bands, cylindrical vessels made of steel protected from corrosion, and similar vessels or tanks made of reinforced concrete. On account of the limitation in space, the subject of tanks can not be included in this publication.

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